Close out report:
Analysis and Modeling of Surfzone Turbulence and Bubbles

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GOALS & OBJECTIVES

Turbulence in the surfzone and nearshore mixes momentum vertically, transmits stress to the sea bed, influences the structure of the cross- and alongshore currents, and controls the suspension of sediment from the sea bed. In many coastal and shelf environments, the sea-bed is the primary source of turbulence due to bottom induced shear. In the surfzone, the breaking-wave generated turbulence likely dominates over bottom generated turbulence. However, the dynamics of turbulence in the nearshore and surfzone under breaking waves is poorly understood.

Realistic three-dimensional simulations of surfzone hydrodynamics and sediment transport, which are currently being attempted, for example, in the recent nearshore NOPP project, will not be possible without at least a rudimentary understanding of nearshore turbulence dynamics. Long term goals include addressing some of the unresolved science issues through analysis and modeling of existing field measurements to quantify turbulence dynamics.

To address nearshore/surfzone turbulence dynamics, this research had two approaches, modeling work and analysis of field data, which has resulted in 3 journal publications (*Feddersen and Trowbridge*, 2005; *Feddersen and Williams*, 2006; *Feddersen et al.*, 2006).

APPROACH

The model development (programming) and testing work was done by the PI (Feddersen), The basis of the coupled turbulence-bubble model is a standard k-ϵ model augmented with a wave-breaking turbulence source terms in an approach similar to that used for open-ocean wave breaking (*Craig and Banner*, 1994), but with the time-dependence of breaking retained. The model is described in detail in *Feddersen and Trowbridge* (2005).

The field campaign consisted of a main instrumented frame was deployed for 2 weeks at the U.S. Army Corps of Engineers Field Research Facility (FRF) at Duck N.C. in approximately 3.2 m mean water depth with the variable tides and wave heights (Fig. 1). At this depth, there was white-capping wave breaking but no depth-limited wave breaking. The main frame was instrumented with a vertical array spanning most of the water column of 3 ADV (Acoustic Doppler Velocimeter) to to measure velocity. These measurements of the vertical structure of turbulence in the nearshore are unique and had not before been attempted in the nearshore region.

Field data analysis included estimating the dissipation from the ADVs, using the frozen turbulence hypothesis and the inertial-dissipation technique (*Trowbridge and Elgar*, 2001). The vertically separated ADVs were used to infer the turbulent momentum fluxes, *i.e.*, $\overline{v'w'}$ (*e.g., Feddersen and Williams*, 2006) that are part of the shear production term in the TKE dynamics.

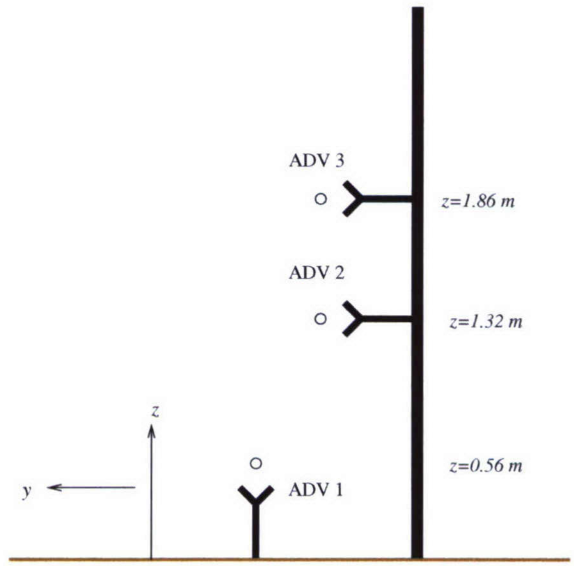

Figure 1: Schematic of the ADV locations. The view is toward offshore ($+x$), and the vertical z and alongshore y coordinates are indicated. ADV 1 is upward looking. The vertical location of the ADV sensing volumes (indicated by the small circle) are given

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RESULTS

This grant has resulted in 3 journal publications, detailed individually below.

Surfzone Turbulence Modeling

The newly surfzone/nearshore turbulence model is able to reproduce the observed non-dimensionalized turbulence dissipation $\epsilon/(g^3h)^{1/2}$ from three different data sets. The nondimensionalization of dissipation collapses the three data sets which come from different beaches and wave conditions (*Feddersen and Trowbridge*, 2005).

Estimating Reynolds Stresses

An important component of testing a turbulence model is developing field estimates of the Reynolds stress component $\overline{v'w'}$. As is discussed in *Trowbridge* (1998), estimation of $\overline{v'w'}$ in surface gravity wave dominated environments requires special methods. *Trowbridge* (1998) developed a $\overline{v'w'}$ estimation method using two current meters and tested it near the bed with two horizontally separated current meters (*Trowbridge*, 1998; *Trowbridge and Elgar*, 2001). *Shaw and Trowbridge* (2001) developed another method for vertically separated sensors with weak wave conditions near the bed off of the continental shelf. However, for the vertical ADV array (Fig. 1), a new $\overline{v'w'}$ estimation method had to be developed, because of problems with the other methods. The *Trowbridge* (1998) method has significant wave bias problems (not shown). The *Shaw and Trowbridge* (2001) method $\overline{v'w'}$ were better but often failed a test of the integrated velocity cospectrum. The new

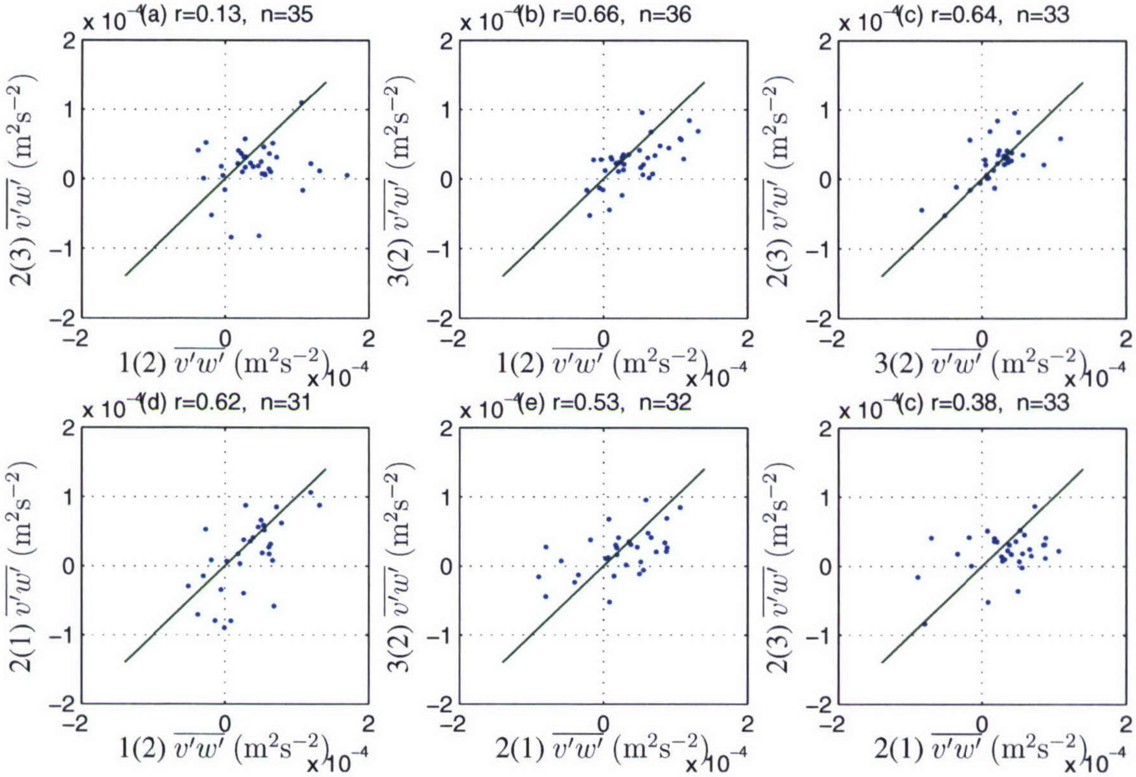

Figure 2: Inter-sensor comparison of *Feddersen and Williams* (2006) estimated $\overline{v'w'}$ for all combinations of vertical location. The correlations and number of good colocated estimates are given.

method, described in *Feddersen and Williams* (2006), is able to reproduce a constant stress layer (*i.e.,* vertically uniform $\overline{v'w'}$) in the wind-driven nearshore environment (Fig. 2).

This work *Feddersen and Williams* (2006) is in press to *J. Atmos. Oceanic Tech.*

Vertical Structure of Turbulent Dissipation in the Nearshore

The next componenet of this research concerns the vertical structure of turbulent dissipation in the nearshore and is now in press to JPO (*Feddersen et al.*, 2006).

The dissipation of turbulent kinetic energy (ϵ) is estimated with a new method (*Feddersen et al.*, 2006) at each of the ADVs (Fig. 1). The mean plus the first EOF captures the majority (91%) of the ϵ variability. The observed ϵ has a maximum at the uppermost ADV, a minimum at the middle ADV, and another maximum but less than ADV 3, at the bottom (Fig. 3). This is consistent with surface generated turbulence due to wind-induced wave-whitecapping influencing ADV 3 and near-bed generated turbulence influencing ADV 1 (see for example *Feddersen and Trowbridge*, 2005).

Further demonstrating that the increased surface ϵ is not due to surfzone depth-limited wave breaking, the ϵ observations are scaled with a surfzone dissipation scaling (*Feddersen and Trowbridge*, 2005) giving the non-dimensional $\epsilon/(g^3h)^{1/2}$. At the same relative locations in the water

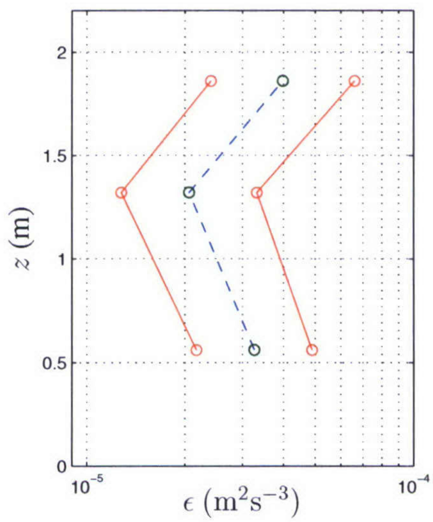

Figure 3: Vertical structure of the log-eof ϵ: mean (dashed) and mean $\pm$ first EOF (solid).

column, these values were much less that other scaled surfzone $\epsilon/(g^3h)^{1/2}$ (*George et al.*, 1994; *Bryan et al.*, 2003). Another process is giving the increased near surface ϵ.

Wind-induced wave whitecapping is likely that process. In a deep lake, *Terray et al.* (1996) found increased ϵ near the surface that scaled as

$$\epsilon H_{\text{sig}}/(\alpha u_*^3) = 0.3(z'/H_{\text{sig}})^{-2} \tag{1}$$

where z' is the distance from the surface, u_* is the friction velocity and α is a constant. This implies that white-capping was inputing turbulence at the surface which diffuses downward resulting in enhanced ϵ relative to law of the wall scaling. The top two ADVs follow this deep-water scaling (Fig. 4a,b). This demonstrates that the processes just offshore of the surfzone that result in increased near surface dissipation are the same wind-induced white-capping wave breaking as in the deep water (*e.g., Terray et al.*, 1996). However the near bed ADV does not follow this scaling and is likely influenced by bottom boundary layer processes.

References

Bryan K. R., K. P. Black, and R. M. Gorman, Spectral estimates of dissipation rate within and near the surf zone, *J. Phys. Oceangr., 33*, 979–993, 2003.

Craig, P. D., and M. L. Banner, Modeling wave-enhanced turbulence in the ocean surface layer, *J. Phys. Oceangr., 24*, 2546–2559, 1999.

Feddersen F., J. H. Trowbridge, A. J. Williams, The vertical structure of dissipation in the nearshore, *J. Phys. Oceangr.,* in press, 2006.

Feddersen, F. and J. H. Trowbridge, The effect of wave-breaking on surfzone turbulence and alongshore currents: A Modeling Study, *J. Phys. Oceangr., 35*, 2187–2203, 2005.

Feddersen F., and A. J. Williams 3d, Direct estimation of the Reynolds stress vertical structure in the nearshore, *J. Atmos. Oceanic Tech.*, in press, 2006.

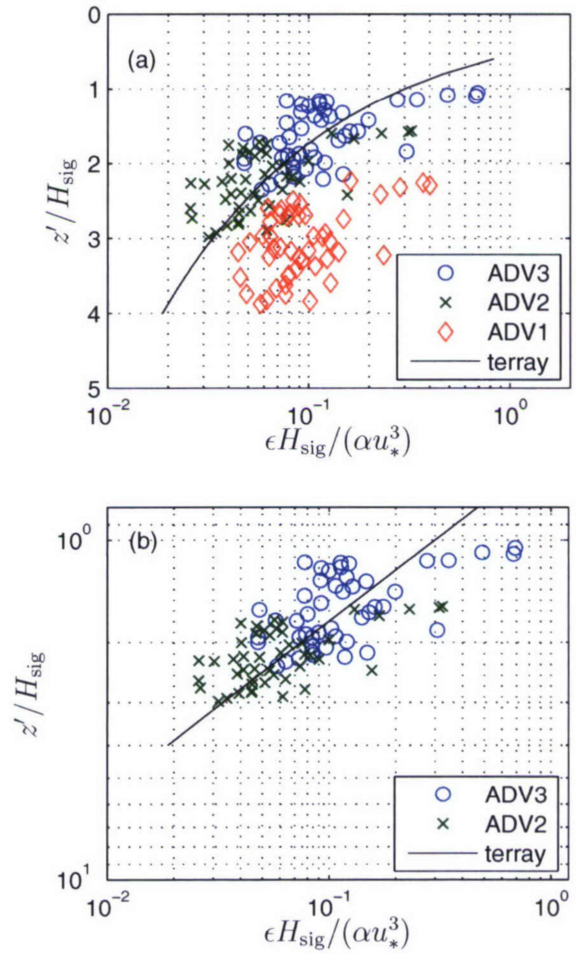

Figure 4: (a) Wave-scaled $\epsilon H_{\mathrm{sig}}/(\alpha u_*^3)$ versus wave-normalized depth z'/H_{sig}. (b) log-log plot of the same. The black curve in (a,b) is the *Terray et al.* (1996) scaling of $\epsilon H_{\mathrm{sig}}/(\alpha u_*^3) = 0.3(z/H_{\mathrm{sig}})^{-2}$.

George, R., R. E. Flick, and R. T. Guza, Observations of turbulence in the surf zone, *J. Geophys. Res., 99*, 801–810, 1994.

Shaw, W. J., and J. H. Trowbridge, The measurement of near-bottom turbulent fluxes in the presence of energetic wave motions, *J. Atmos. Oceanic Technol.*, *18*, 1540–1557, 2001

Terray, E. A., M. A. Donelan, Y. C. Agrawal, W. M. Drennan, K. K. Kahma, A. J. Williams, and P. Hwang, Estimates of kinetic energy dissipation under breaking waves, *J. Phys. Oceangr., 26*, 792–807, 1996.

Trowbridge, J. H, On a technique for measurement of turbulent Reynolds stress in the presence of surface waves, *J. Atmos. Oceanic Technol.*, *15*, 290–298, 1998.

Trowbridge, J. H., and S. Elgar, Turbulence measurements in the surfzone, *J. Phys. Oceangr., 31*, 2403–2417, 2001.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
29-11-2006	Final Technical Report	01-02-2004 - 30-09-2006

4. TITLE AND SUBTITLE
Analysis and Modeling of Surfzone Turbulence and Bubbles

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-04-1-0218

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Falk Feddersen

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

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Office of Naval Research
Attn: Dr. Thomas G. Drake, ONR 321
875 N. Randolph Street
One Liberty Center
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
surfzone, nearshore, turbulence, modeling, observations

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Falk Feddersen
Unrestricted	Unrestricted	Unrestricted	None	6	19b. TELEPHONE NUMBER *(Include area code)* (858) 534-4345

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18